National Aeronautics and Space Administration

In-Space Power and Propulsion

Briefing to the NASA Advisory Council HEOC
March 29, 2017

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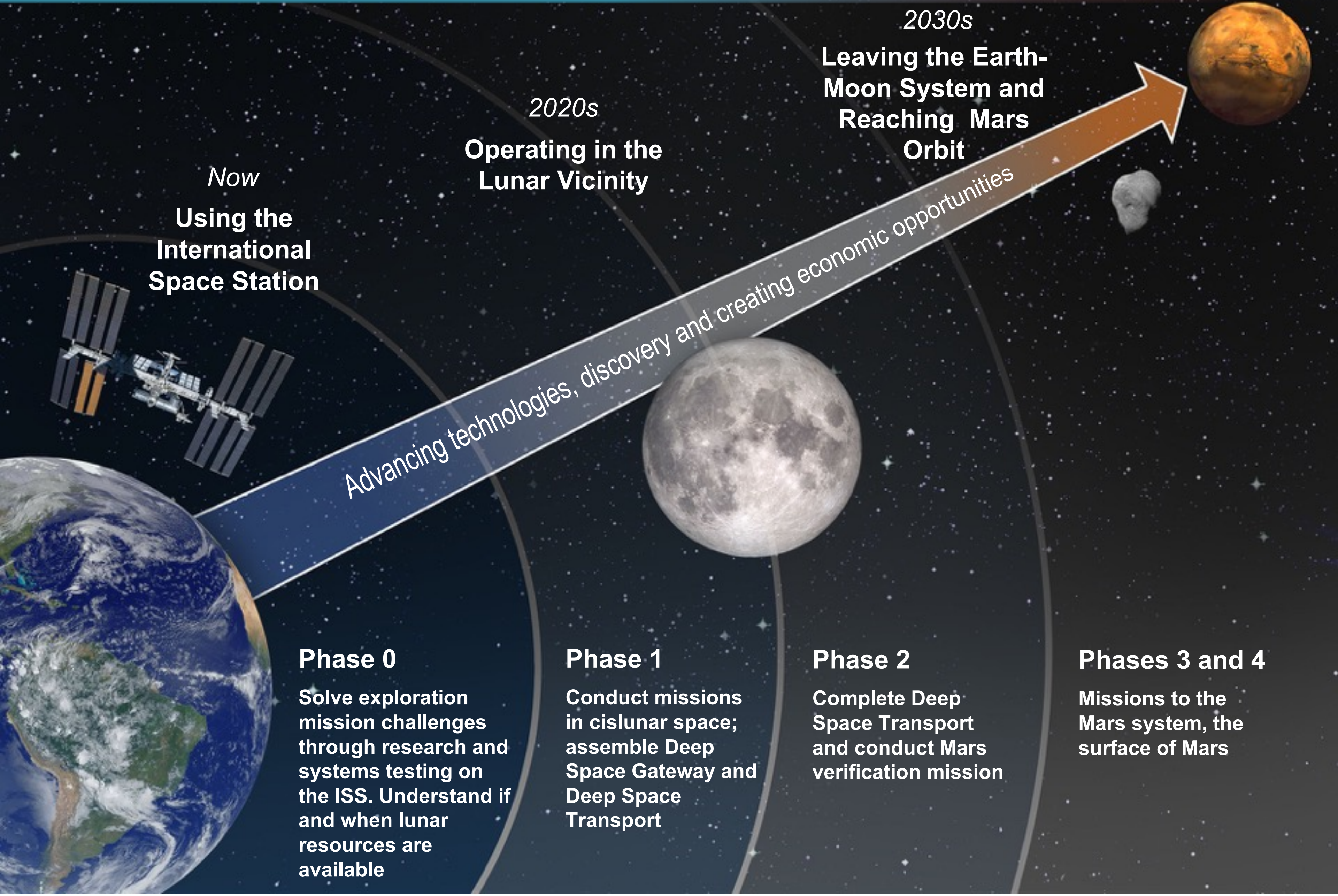
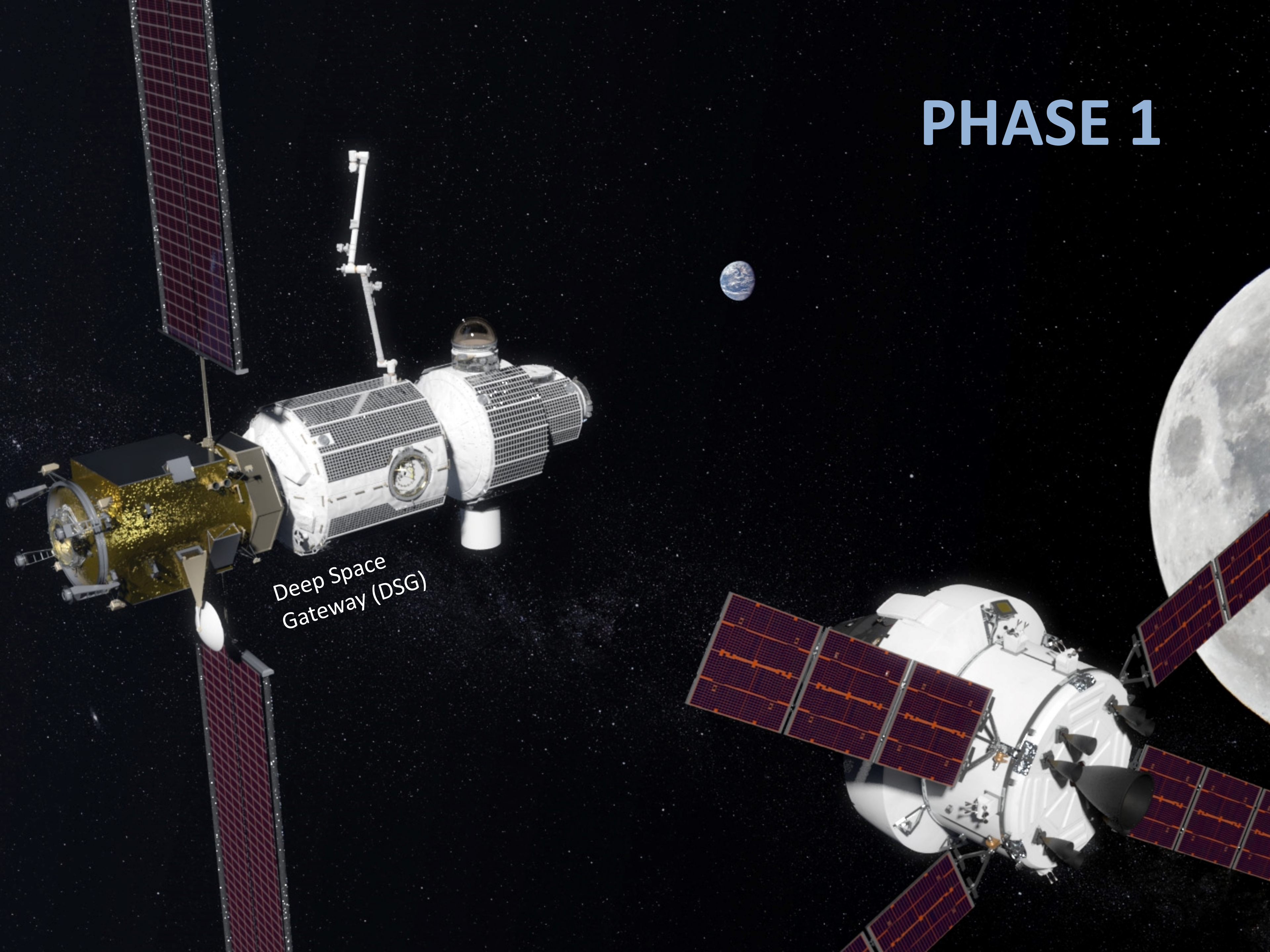
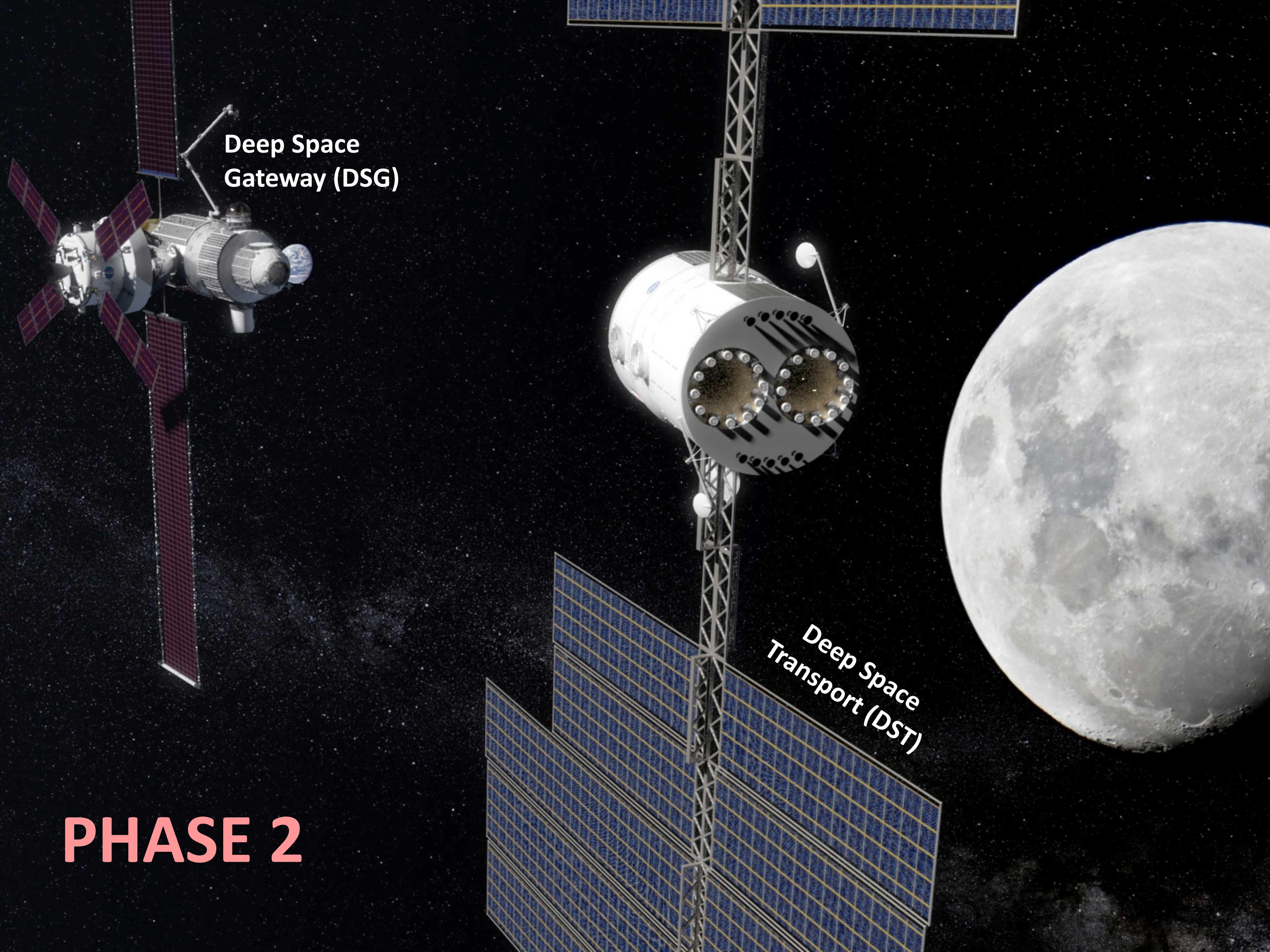
Exploring Space In Partnership



PHASE 1




Deep Space
Gateway (DSG)
Deep Space
Transport (DST)
PHASE 2

Approach

- **NAC request for in-space power and propulsion**
- **This briefing is focused on applicability of solar electric propulsion (SEP) on ARRM for human exploration**

Asteroid Redirect Mission Advanced SEP Demonstration

- **Relevant Asteroid Redirect Mission Objectives**

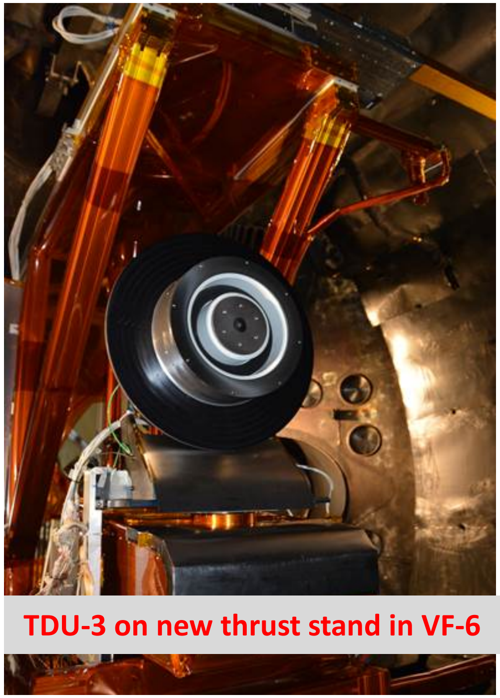
  1. 'Conduct a human exploration mission'…., 'providing systems and operational experience required for human exploration of Mars'.

  2. Demonstrate an advanced solar electric propulsion system, enabling future deep-space human and robotic exploration with applicability to the nation's public and private sector space needs.

- **Relevant Asteroid Redirect Robotic Mission (ARRM) Level 1 Requirements**
  – ARRM shall develop and demonstrate a high-power, high-total impulse solar electric propulsion (SEP) system with an input power level of at least 40kW and a useable capacity of 5 t of propellant that is extensible to future human and robotic missions to Mars at a power level of at least 150 kW.
  – ARRM shall demonstrate solar array technology with the power-to-mass ratio, stowed volume efficiency, deployed strength and radiation tolerance applicable for future robotic and human missions to Mars.

SEP Risk Reduction Testing (1)

- Completed hardware installation for Vacuum Facility (VF-6) thruster testing.
  - New xenon flow panel, data acquisition, breakout box, cabling (power and sense), thrust stand, thruster and plasma diagnostics mounts, and power and instrumentation racks
  - Installed plasma diagnostics suite inside VF-6
  - Installed VACCO XFCM (Xenon Flow Controller Module) inside VF-6 to support AR AEPS early system test
- Completed Technology Demonstration Unit 3 (TDU-3) Thruster assembly and installed in VF6
- TDU-3 was successfully fired. Thruster operated up to 500 V, 12.5 kW with nominal performance
  - Minor issue with electrical isolation near the propellant isolator precluded operation at 600 V
    - Leak was identified in the propellant isolator and corrected
  - Chamber was opened to assess the electrical isolation, and to switch to the M26-BN (Boron Nitride) discharge chamber
    - TDU-3 will be fired in February, diagnostics checked-out



TDU-3 on new thrust stand in VF-6

TDU-3 in VF-6

SEP Risk Reduction Testing (2)

- Second M26 BN channel shipped to JPL
  - Will be used in TDU-2
- Started planning for Wear Test 2 with TDU-3 in VF-5
  - Main objectives are to quantify wear and performance trends to identify unknown failure modes and support validation of service-life models; quantify deposition rate of back-sputtered facility material
  - Currently planning for March through July (TBR) test

New Xenon feed panel

- A thrust vector probe concept was presented to the thruster team for use in VF-5 and VF-6.
  - The team agreed that the concept should proceed to detailed design and fabrication
  - The probe will to be ready for use in June.
- 6 total Developmental Anomaly Reports (DAR) being tracked by Safety & Mission Assurance (S&MA)
  - Tracks anomalies in developmental testing, helps identify trends, identifies cause and corrective action, not as rigorous as for flight HW
  - 1 closed, 5 open

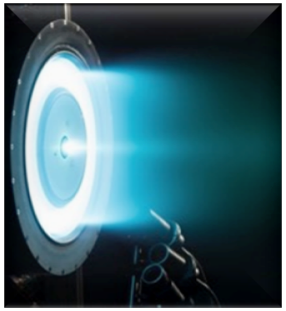
VF6 new power & instrumentation racks and DAQ computer

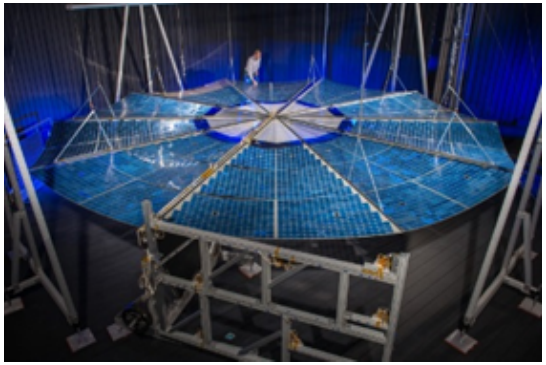
ARM SEP Contributions

- **Advanced SEP systems are part of the foundation for human exploration plans, including ultimately a transportation system for human exploration to and from Mars**
  - STMD’s Advanced Electric Propulsion System thruster power level on ARM supports lunar vicinity early phase needs based on studies to date
  - Direct applicability to enhancing commercial spacecraft market, enabling NASA as a marginal buyer
- **Advanced Electric Propulsion Systems, compared to chemical**
  - 4-6 x higher Isp
  - 5-10 x less propellant mass for equivalent missions
  - Magnetic shielding design enables long life operation (years)
- **High powered thrusters will operate at ~2.5 times the power level of the highest powered electric thrusters now in use**
- **Solar array systems, compared to current state of the art**
  - 2x lighter
  - 4x less stowed volume
  - 4x greater radiation tolerance
  - 20x greater deployed strength

ARM SEP Technology Demonstration Contributions

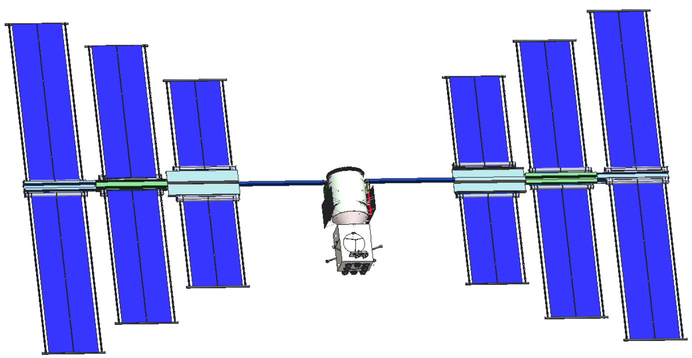
- **Demonstrate performance and operations in deep space**
- **Characterize high power (12.5 kW) next generation Hall thrusters**
- **Characterize solar arrays (high power density, >130 W/kg) > 30 kW beginning of life**
- **Integral HP-SEP system including thrusters, arrays, bus, and payloads as they operate as an integrated system**
  - Quantify xenon plume and thruster electromagnetic interference effects
- **Demonstrate Δ V**
  - Confirm throughput EP capability and lifetime of overall flight system
  - Xenon 2600 - 3000s and >23,000 hr

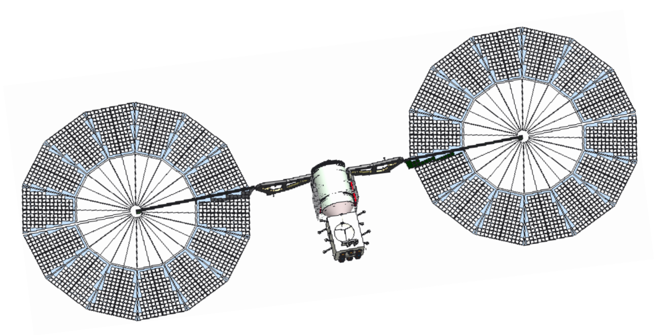




ARM Scalability to Deep Space Human Exploration

- **High-power, 40-kW system would be a step up from current technology and on the path to much higher power systems.**
  - Range of powers could be as high as 150 kW to 300 kW
- **Electric propulsion technology scalable**
  - Several Hall thrusters of higher power (~50kW) have been validated in a laboratory environment
  - Power Processing Unit (PPU) design is modular
  - HEOMD reference mission scenarios use Isp range ~2000-3000 seconds
- **The solar array would be scalable beyond the 90kW class with the use of additional wings.**
- **The power per thruster/PPU string is a mission dependent system-level trade between fewer higher-power strings and more numerous lower-power strings.**





High Power SEP Integrated System Demonstration Outcomes

ARRM SEP bus planned to provide:

- **NASA and industry design, building, test and operations of a 40kW SEP spacecraft**
  - Solar array including packaging, deployment, and flight dynamics
  - End to end high power multi-string SEP system design and performance
  - PPU design
  - Cathode design
  - Power management system with high power and high voltage
  - Thermal design at various solar ranges including with eclipses
  - Spacecraft and xenon plume interaction analysis and design
  - Mission operations including autonomous operations and fault management
- **Proof of a deep space operational capability that is directly applicable to wide range of robotic and human spaceflight missions**

NASA